TESTING AND ANALYSIS DONE IN SUPPORT OF THE DEVELOPMENT OF A CONTAINER FOR ON-SITE WEAPON DEMILITARIZATION

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prepared for

27th DDESB Seminar
Department of Defense Explosives Safety Board

August 21, 1996

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **21 AUG 1996**	2. REPORT TYPE	3. DATES COVERED **00-00-1996 to 00-00-1996**

4. TITLE AND SUBTITLE **Testing and Analysis Done in Support of the Development of a Container for On-Site Weapon Demilitarization**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Southwest Research Institute,6220 Culebra Road,San Antonio,TX,78228-0510**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM000767. Proceedings of the Twenty-Seventh DoD Explosives Safety Seminar Held in Las Vegas, NV on 22-26 August 1996.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**15**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

1.0 INTRODUCTION

Southwest Research Institute (SwRI) was contracted by the U.S. Army Engineering and Support Center, Huntsville (formerly the Huntsville Division, Corps of Engineers) to develop, fabricate, and proof test a container which can be used by explosives ordnance disposal (EOD) personnel for on-site demolition of a given size and number of munitions.

The first step of the project was to develop a container concept and to perform preliminary design. The concept container consisted of a cylindrical steel confinement with elliptical ends and fragment mitigating materials inside the container for protection of the outer cylindrical shell from fragment impacts. Based on this concept, tests were performed to define blast and fragment mitigation approaches. Three sets of concept tests were conducted. The first set of tests was to evaluate fragment mitigating materials by firing fragments at mitigating material. The second set of tests was used to evaluate blast mitigating methods including the use of water bags and blasting mats. The final set of concept tests used a cylindrical section and the blasting mats to evaluate the effectiveness of the mats at resisting the combined blast and fragment effects in the cylinder.

2.0 DEVELOPMENT TESTS

2.1 Introduction

Three concept test series were conducted at the SwRI explosives and ballistics ranges. Gun tests were performed to establish the performance of two candidate fragment mitigating materials against single, high velocity fragments predicted by analysis. Preliminary concept tests were performed to measure the loads (pressures) produced with and without fragment mitigating materials and quasistatic pressure mitigating materials such as water or foams in the container cylinder. Fragment mat degradation tests were conducted to demonstrate and document the longevity of the fragment mitigation mats when subjected to 5 successive loadings with a set of the design munitions. After fabrication of the final prototype, proof tests were conducted to validate the container design for safe and reliable performance.

2.2 Gun Tests (Concept Test Series 1)

2.2.1 Gun Tests Objectives

The gun tests were performed to establish the performance of 2 "worst case fragments" against a steel/wire rope blasting mat and against a rubber tire blasting mat. The mats were designed (thicknesses selected) to resist the penetration of 75% and 95% mass fragments as determined by the Gurney and Mott equations, based on the case thicknesses of an 81 mm mortar.

2.2.2 Gun Test Setup

All gun tests were conducted with the 30 mm smooth bore gun, used with HC-33 powder. Preliminary estimates indicated that a 3:1 ratio of powder to "package" weight will produce the desired velocity of approximately 2 km/sec in the 30 mm smooth bore. Make screens (3 between barrel and target, 2 behind the target as required) were used to record velocities. Outputs from the screens were recorded with counters. Targets supplied by the manufacturer were roughly 3 ft x 3 ft for the rubber, and 4 ft x 4 ft for the wire rope. A sabot stripper plate was required to prevent the sabot from striking the target. Fragment residual velocity was measured, if observed.

2.2.3 Gun Test Results

Ten gun tests required in the first set of concept tests were completed. All tests were performed by shooting a 0.10 oz projectile at an intended velocity of 5900 fps into a candidate fragment mitigating material. The projectile simulates the worst case fragment at a 95% confidence level from a 81 mm mortar. This fragment is considered representative for other munitions that may be demolished in the demolition container since it causes a worse case calculated penetration through steel and rubber fragment mitigating materials for all such munitions considered.

Seventy-five percent and 95% probable munition fragments were identified which cause worst case calculated penetration through the two candidate blast mats. Table 2.1 shows a list of the munitions which were considered in our analysis. This is the list of possible munitions that can be detonated in the demolition container. The blasting mats were modeled as best as possible with existing penetration equations, but the results calculated with these equations must be regarded as approximate. The THOR equations, using constants for an unbonded nylon target, were used to estimate fragment penetration through the rubber mats, and the penetration equation for a mild steel plate target in TM5-1300 (which is also used in TM-5-855-1) was used to estimate penetration through the wire rope mats. The rope diameter (5/8 inch) was used as the target thickness.

Table 2.2 shows the fragments from munitions in Table 2.1 which caused worst case penetration in one or the other of the two mats at the 75% and 95% confidence levels. These fragments were identified by calculating penetration of the 75% and 95% probable fragments from five different points along the length of each munition in Table 2.1 (i.e., at the fuze, nose, side, base side, and base of the munition). The Gurney and Mott equations were used to determine fragment mass and velocity. The casing thicknesses at each of the five points along the length that were used as input into the Gurney and Mott equations were carefully scaled off drawings of the munitions in TM 43-0001-28. Since scaled dimensions were used, the calculated fragments must be regarded as approximate. Ninety-five percent probable fragments from the nose and sides of munitions in Table 2.1 penetrated through one thickness of both mats with calculated residual velocities that varied between zero and 400 fps, which is less than 10% of the initial velocity. None of the base of fuze fragments penetrated the mats. There was no calculated residual velocity for any

of the 75% probable fragments for a single mat thickness.

Considering the approximations and assumptions that were used in the calculation process, the difference in the penetration caused by the fragments from the seven munitions in Table 2.1 is relatively insignificant. This observation, and the limited capacity of our propellant gun to shoot at velocities over 6,000 fps narrowed our choice of the proposed simulated fragments for the propellant gun tests. The 75% and 95% probable fragments for the 81 mm mortar (2.1 lbs of high explosive) were chosen as shown in Table 2.2. The fragments were manufactured from 3/16 inch and 5/16 inch mild steel circular bar stock with L/D ratios very close to 1.0.

Table 2.1. Anticipated Munitions in Demolition Container

Munition	Length (in)	High Explosive Weight (lb)	Net Explosive Weight (lb)	Total Munition Weight (lb)
57 mm HE M306 A1 - Recoilless	17.54	0.55 Comp B	1.55	5.46
60 mm HE M49A5 - Mortar	14.71	0.79 Comp B	0.839	3.90
60 mm HE M49A4 - Mortar	11.59	0.42 Comp B	0.839	3.25
75 mm HE M309A1 - Recoilless	28.92	1.49 TNT	4.79	22.37
75 mm HE M48 - Howitzer	23.50	1.49 TNT	1.49*	18.24
81 mm HE M374A2 - Mortar	20.84	2.10 Comp B	2.426	9.34
81 mm HE M43A1 - Mortar	13.32	1.29 Comp B	1.673	7.15

* TM 43 shows a significant amount of propellant in addition to 1.49 lb of HE

Table 2.2 Calculated Worst Case Fragments from Munitions in Table 2.2

Munition in Table 2.2	Worst Case 75% Probable Fragments	Worst Case 95% Probable Fragments
57 mm	0.003 oz at 7240 fps	0.015 oz at 7240 fps
81 mm	0.02 oz at 5922 fps*	0.10 oz at 5922 fps*

* Proposed fragments for propellant gun tests on candidate fragment mitigating materials

The two fragment mitigating materials which were tested are: 1) a steel wire rope blasting mat (20 psf, \$40/sf, 2 inches thick), manufactured by weaving together 5/8 inch diameter wire rope strands; and, 2) a rubber blasting mat (23 psf, \$8/sf, 4.5 inches thick), manufactured by stacking 4.5

inch wide strips of recycled tire tread on steel cable.

Based on the results from these tests, it was concluded that both mats would probably stop all, or nearly all, fragments from a 81 mm munition. The reusability of the mats, and their performance during simultaneous impact from many fragments, intense heat, and blast loading which will occur during close-in loading from an actual munition, were not judged on the basis of these tests. Further gun testing was not recommended because of the difficulties involved in performing these tests and the unknown correlation between the response of mats during the gun tests and their response during actual munition testing. Arena test data (accomplished under a separate test at SwRI) provided a much more comprehensive indication of the suitability of the two candidate fragment mitigating materials.

2.3 Concept Tests to Determine Water/Foam Effectiveness (Concept Test Series 2)

2.3.1 Concept Test Series 2 Objectives

The first preliminary concept tests in this series were conducted to verify the performance water to attenuate the shock and gas pressure in the disposal chamber. The predicted response levels of the 42 in cylindrical vessel was also confirmed. Additionally, these tests quantified the attenuation of shock and gas pressure provided by the fragment mitigating material.

2.3.2 Concept Test Series 2 Setup

The fixture consisted of a bottom and top plate with supports for the fragment mitigating material. The top plate and cylinder had ports for shock and quasistatic pressure measurement, as well as small vents for pressure relief and for firing line introduction into the cylinder. Only one mat material was used in these tests (the steel mat), having been selected during gun and arena tests. The bottom 1/2 in plate was placed first, followed by the cylinder. The mat material was then positioned in the cylinder (having been provided by the manufacturer in a closed cylindrical configuration). The bottom mat was placed on the plate first, then the cylinder. Next the explosive charge or munition was hung, and finally, the top plate was positioned, and 4 2-ton concrete blocks were placed on the top plate tubes to provide confinement.

PCB 102 A03 shock pressure gages were mounted in the steel "doughnuts" and mounting tube and flange, prior to attachment to the cylinder and top plate. Kulite HEM-375 pressure gages were used for quasistatic pressure measurement. These gages were mounted in a similar manner, with the addition of a 0.25 in. mechanical filter disc (3 1/16 in holes in a 0.25 in aluminum "doughnut"). Conditions for each test are listed in Table 2.3. Bare C-4 explosive was used in these tests.

Table 2.3. Concept Tests with Bare High Explosive in Simulated Demolition Container

Test Number	Test Conditions
1 (trial test)	1 lb C4 bare explosive, no mitigating materials
2 (trial test)	4 lbs TNT equivalent bare explosive, no mitigating materials
3 (trial test)	4 lbs TNT equivalent bare explosive, no mitigating materials
4 (baseline)	4 lbs TNT equivalent bare explosive, no mitigating materials
5	Bare explosive (4 lbs TNT) with water bags at 5 lb water/1 lb TNT explosive weight ratio
6	Bare explosive (6 lbs TNT) with water bags at 6 lb water/1 lb TNT explosive weight ratio
7	Bare explosive (4 lbs TNT) with water bags at 5 lb water/1 lb TNT explosive weight ratio and a steel blasting mat
8	Bare explosive (6 lbs TNT) with water bags at 5 lb water/1 lb TNT explosive weight ratio and a steel blasting mat
9	Bare explosive (4 lbs TNT) with water bags at 5 lb water/1 lb TNT explosive weight ratio and an enlarged, strengthened steel blasting mat (mat outside diameter equal to test container inside diameter)

2.3.3 Concept Test Series 2 Results

Because it is virtually impossible to completely isolate the gages from the effects of the high frequency structural response, the amplitude of the "noise" level in the measured quasistatic pressure histories was a significant percentage of the quasistatic pressure itself. Therefore, all measured quasistatic pressures are considered as estimates and are based on the shock pressure gage measurements. Table 2.4 shows a summary of the shock pressure histories and estimated peak quasistatic pressures measured during Tests 3 through 8 at gages which functioned properly in each test. Typically, the unmitigated blast pressure history at Gage P1, which was on the cylinder in the same cross section with the charge, consisted of a single large pressure pulse followed by numerous low amplitude reflections. The unmitigated blast pressure history at gage P2, at the center of the top plate, typically consisted of three high amplitude pulses apparently caused by the incident shock wave, the focused reflection off the sides the cylinder, and the reflection off the bottom plate. The presence of water bags mitigated the shock pressures, and in some cases eliminated pressure pulses, but also caused some additional short duration high amplitude pressure pulses. The combined presence of water bags and a set of steel wire rope blasting mats around the charge (i.e., a 2 ft diameter by 3 ft long cylindrical mat with flat mats over the top and bottom) was very effective at mitigating the incident pressure pulse and nearly eliminating reflected shock pressure pulses.

Table 2.4. Summary of Blast Pressures Measured During Second Concept Test Series

Test No.	Charge Weight (lbs. of C4)	Measured Shock Pressure Pulses										Estimated Quasistatic Pressure
		Gage P_1 on Cylinder ++				Gage P_2 on Top Plate ++						
		P_1 (psi)	i_1 (psi-sec)	P_2 (psi)	i_2 (psi-sec)	P_1 (psi)	i_1 (psi-sec)	P_2 (psi)	i_2 (psi-sec)	P_3 (psi)	i_3 (psi-sec)	(P_g) (psi)
3	3.13	**	**	**	**	6,200 (0.2)	0.45	8,200 (0.7)	0.6	3,750 (1.4)	0.55	350
4	3.13	7,900 (0.12)	0.45	n/a	n/a	11,700 (0.24)	0.36	8,200 (0.63)	0.66	5,800 (1.45)	0.5	350
5	3.13	7,300 (1.65)	0.04	n/a	n/a	13,000* (0.23)	0.35	13,000* (0.28)	0.32	4,700 (0.35)	0.38	100
6	4.7	22,500 (0.6)	0.55	22,000 (0.76)	0.58	5,800 (0.43)	0.03	3,000 (0.6)	0.05	+	+	+
7	3.13	390 (0.55)	0.055	n/a	n/a	425 (0.5)	0.1	200 (2.6)	small	n/a	n/a	100
8	4.7	625 (0.2)	0.03	n/a	n/a	1,075 (0.4)	0.2	450 (2.3)	small	n/a	n/a	100

The primary purpose of the tests summarized in Tables 2.3 and 2.4 was to investigate the effects of shock mitigating materials. Based on information in the literature, and discussions with CEHNC, the mitigation materials investigated during the test series were water bags in contact with the charge and the steel wire rope blasting mat. A comparison of Tests 4 and 5 illustrates the effectiveness of the water bags. Comparison of the measured pressure pulses at gage P1 and the measured quasistatic pressures for these two tests in Table 2.4 shows that the water bags are effective at reducing the quasistatic pressure and the peak shock impulse in some directions by a very significant amount. The arrival time of the peak pressure is also slowed significantly by the presence of water. However, as a comparison of the peak pressures and impulses measured at gage P2 shows, the shock pressures in some directions can be amplified very early in time when water bags are placed around the charge. The three primary pulses at gage P2 in Test 5 arrive very early in time compared to the three pulses in Test 4 so that it is probable that these pulses in Test 5 are reflections off water bags that are focused towards the top plate, rather than reflections off the walls and bottom plate of the container. There are no significant pulses measured at gage P2 in the Test 5 data corresponding to reflections off the walls and bottom plate of the container, which is consistent with the very small impulses measured on the container wall at gage P1. The water bags were placed with the charge in a relatively flat net for Test 5, so that gravity forces caused more water to be around the sides and bottom of the charge than over the top. Therefore, it seems that this uneven distribution of water around the charge may have focused the blast towards the top plate.

Test 6 was conducted with a larger charge weight (6 lbs equivalent TNT rather than 4 lbs) and a more even packing of water around the charge. The water and charge were placed in a cardboard box for this test, with three bags placed flat on the bottom of the box, the charge and four water bags (one on each side of the charge) placed in the middle of the box, and two water bags

placed flat over the charge. The box was approximately a 1 ft cube, and each water bag weighed approximately 4 lbs. Only the first millisecond of the pressure history was measured during Test 6 before exceptionally high accelerations of the test structure evidently failed (blew out) both pressure gages. However, it is obvious, whereas in Test 5, the peak pressures and impulse on the top plate (at gage P2) were much larger than those on the cylinder (at gage P1), the opposite was true in Test 6. The very high peak pressures measured on the cylinder in Test 6 (peak pressure and impulse correspond to those for a scaled standoff of 0.5 ft/lb$^{1/3}$ rather than the actual 0.96 ft/lb$^{1/3}$) indicate that the shock pressure pulse may have been focused through the air gaps between the four water bags around the sides of the charge.

Test 7 was conducted with a steel blasting mat and the same charge weight (4 lbs equivalent TNT) and water weight used in Test 5 with approximately the same arrangement of water bags as Test 5. Therefore, it is comparable to Test 5 except that it measures the additional mitigation provided by a steel wire rope blasting mat. A comparison between Tests 5 and 7 indicates the effectiveness of the blasting mats in reducing shock pressures on the test container. The mats were very effective at reducing the high pressure, very short duration pulses measured in previous tests with water bags since only small peak pressures (less than 500 psi) were measured at both pressure gage locations. Unfortunately, about twelve strands around in the wire mat closest to the charge were severed by the blast pressures. The mat was held in a cylindrical shape by a pipe that was inserted through loops in either end of the mat. The pipe was indented by forces transmitted through the wire loops from hoop response of circular strands in the mat. The flat mats covering the top and bottom of the cylindrical mat were not significantly damaged. These mats were at a standoff of 1.5 ft, as opposed to a 1 ft standoff to the portion of the cylindrical mat which failed. Also, they were not constrained in any manner against the applied blast pressures since they were just sitting on the top and bottom of the cylindrical mat. It is not surprising that the blasting mats provide significant shock pressure mitigation because their geometry, which allows shock pressures to filter through the weave but has virtually no horizontal lines of site through the weave, is similar to that of a suppressive shield.

In Test 8, a 6 lb equivalent TNT charge weight was detonated in the container with both 30 lbs of water bags adjacent to the charge and the same set of blasting mats used in Test 7. The broken strands in the cylindrical mat were pulled together as best as possible, and the hole was oriented in the direction diametrically opposite the pressure gage (P1) in the cylinder. The pipe holding the two ends of the cylindrical mat together was removed, and light banding wire was used to hold the mat in a cylindrical shape and to restrain the severed and splayed ends of the broken strands without providing any significant structural confinement. Test 8 was conducted to determine what additional damage would occur to the cylindrical mat when it was unconstrained and to measure the blast pressures on the container from 6 lbs TNT after they are mitigated by both water bags and a surrounding steel wire rope blasting mat. Due to the condition of the blasting mat, the measured blast pressures are considered representative for an arrangement of blasting mats which is relatively free to deform under blast loading (i.e., the top mat could fly upward and the cylindrical mat could

"unfurl" so that significant gaps form in the mat system at times later than fragment arrival times). As the information in Table 2.5 indicates, the measured blast pressures were approximately twice those measured during Test 7, but they are still quite small (less than 1100 psi) compared to the unmitigated blast pressures from 4 lbs of equivalent TNT (Tests 3 and 4). The blasting mat was damaged during this test to almost the same extent as it was during Test 7, with the smaller charge weight. Therefore, the fact that it was held in the cylindrical shape by the pipe was not the primary reason the observed damage occurred in Test 7. Apparently a local response occurred in the blasting mats during both tests. The top mat was deformed (curled into a half cylinder shape) by the blast loads during Test 8, and a few strands were broken.

Several additional tests, where bare high explosives were detonated in a confined volume modeling the demolition container, were subsequently performed in this series to determine the effectiveness of a new blasting mat against the blast pressures from bare explosives. The new blasting mat was a steel wire rope blasting mat, woven in a continuous cylinder from 0.75 in diameter wire rope with an inside diameter of 3 ft. It was similar to the cylindrical mat used in Tests 7 and 8 of the second concept test series, except that the inside diameter and wire rope diameter were both significantly larger (the previous cylinder diameter was 2 ft and the previous wire rope diameter was 5/8 inches). A larger, stronger mat was used in the additional tests because blast pressures caused localized failure of the previous mat near the charge during Tests 7 and 8.

Two uninstrumented tests were conducted outside (free-air), where spherical charges of C4 explosive equivalent to 2 lbs and 4 lbs TNT were detonated inside the blasting mat, and one instrumented test (Test 9) was conducted in the same test container used for the second series of concept tests. Water bags were not placed around the charge during the two exterior uninstrumented tests; however, water bags were placed around the charge during the test in the test container. No damage was observed in the mat during the two free-air tests. Minimal damage was observed during the enclosed test in the test container consisting of several broken wires in some of the wire rope strands. This compares to between ten and twelve broken ropes in the smaller blasting mat used during Tests 7 and 8. (Please recall the "wires" refer to individual drawn wires; "strands" refers to a twisted assembly of wires; and "ropes" refers to a twisted assembly of strands). Blast pressures were measured at the same gage locations used for all previous tests in the second test series (Gage 1 in the sidewall of the test container and Gage 2 in the top plate of the container) during Test 9. Test 7 was an identical test except the smaller blasting mat was used in the test. The peak pressure and impulse is larger at the gage on the sidewall in Test 7, but the opposite is true at the gage on the top plate. Since the larger diameter cylindrical mat used in Test 9 barely fit within the test container, we hypothesize that the peak shock pressure against the sidewall was greater in Test 9 because there was very little space for the small focused shock waves that propagate through the weave of the blasting mats to dissipate before hitting the wall. In Test 7, the outside of the blasting mat was approximately 7 inches from the sides of the test container. The difference in peak pressure applied to the top plate is evidently caused by the fact that two stacked top mats were used over the top of the cylindrical mat in Test 9, whereas only a single top mat was used in Test 7. In both cases the

explosive was surrounded by a cylindrical mat on the sides and by flat mats which cap the top and bottom of the cylindrical mat. Stacked mats were used in Test 9 because we were trying to cover a circular area with thin rectangular mats, so the mats had to be overlapped in the center in order to accomplish this. The peak pressure and impulse at the sidewall gage, where pressures increased in Test 9 relative to Test 7, are still approximately one fifth of the values assumed for preliminary design.

In summary, results from Tests 3 through 8 of the second set of concept tests show that the blasting mats are very effective at mitigating shock pressures on the test container walls, and the water bags seem to be effective at reducing the overall shock impulse on the surrounding walls and the peak quasistatic pressure. The water bags tend to reduce the summed impulse at both gages over a 1 to 2 millisecond duration, but the peak pressure and impulse in the first peak, or first series of peaks which arrive within tenths of milliseconds, is enhanced in some directions compared to the first peak measured for the corresponding case without water bags. Therefore, the water bags cause very significant shock pressure reduction in some directions (reduced impulse in primary shock pulses by factors of 10), while causing enhanced peak shock pressures in other directions. Since there were only two shock pressure gages in the container, the extent of the area exposed to enhanced shock pressures when water bags are used is not clear. The water bags also caused a significant reduction in the estimated peak quasistatic pressure (approximately by a factor of three). The blasting mat, in combination with the water bags, provided excellent shock pressure mitigation at both shock pressure gages, but the mats suffered such severe damage from both 4 lb and 6 lb equivalent TNT charge weights that they would not be reusable after demolition of munitions causing similar close-in shock pressures.

The final three tests performed showed that a cylindrical steel wire rope blasting mat, constructed with stronger wire rope and a larger diameter, can withstand the blast pressures from a 4 lb equivalent TNT explosion in the test container which models the demolition container without significant damage. Smaller diameter cylindrical mats constructed with thinner wire rope that were used in Tests 7 and 8 in the same test container sustained very significant damage when subjected to the same loading used in the earlier tests. The results from Test 9 also indicate that somewhat higher loads occur on the sidewall of the test container when a larger diameter cylindrical mat is used, and that the use of stacked blasting mats above the explosive significantly reduces the peak shock pressure applied to the top plate of the test container. In all cases blast pressures measured in the test container that have been mitigated with water bags and a blasting mat around the charge are much less than those from a bare explosive, and also much less than the conservative pressure histories assumed for preliminary design of the demolition container.

2.4 Fragment Mat Degradation Tests (Concept Test Series 3)

2.4.1 Mat Degradation Test Objectives

Six tests were conducted with actual 57 mm munitions (3 in each test) to evaluate the ability of the selected steel mats to sustain repeated concentrated loadings and fragment impacts. The tests allowed mat replacement/repair guidance to be developed for vessel operations.

2.4.2 Mat Degradation Test Setup

These were uninstrumented tests, except for residual velocity screens. The mats (top, bottom, and cylindrical) were inspected prior to each test. The condition of the mats was recorded photographically and was documented as penetrations, tears, rips, or hole sizes. Any repair or replacement prior to successive tests was described completely and documented.

These tests were conducted inside a large concrete box culvert to provide fragment protection at the test range. This enclosure did not effect the loads applied to the mats.

2.4.3 Concept Test Series 3 Results

The first test from the third concept series assessed the proposed fragment mitigating material based on testing with actual munitions. Three 57 mm munitions were simultaneously detonated nose down inside a double layer of steel wire rope blasting mats. Two cylindrical steel wire rope blasting mats were placed around the munitions, and a double layer of flat mats were placed over the top and bottom of the cylindrical mats. Table 2.5 summarizes the test set-up and results. The explosives were taped together side-by-side, so that maximum blast loads on the cylindrical blast mats occurred at 120 degree intervals around their circumference. The inside cylindrical mat was at a standoff of approximately 9 inches from the center of the closest munition. Thin steel panels were used as witness panels around the outside of all blasting mats. The test was conducted in a large enclosed area, so that any fragments penetrating the mats would be contained by surrounding steel plates and earth cover.

The damage to the blasting mats during the test was more extensive than expected. The inside cylindrical blasting mat was severely damaged by the blast pressures and fragments from the munitions. All the strands were broken in the three regions closest to the munitions, which were exposed to the largest blast pressures, so that large holes occurred at 120 degree intervals around the circumference of the inner mat. Almost all strands in the cross section with the munitions were either severely damaged, with many frayed wires, or entirely severed. A few strands in the outside cylindrical mat were damaged or severed by fragments, but these strands were widely distributed around the mat and all other wires appeared to be undamaged. The witness panel around the outside cylindrical mat had approximately five holes where fragments passed through both mats with enough

velocity to perforate the 16 gauge panel.

Table 2.5. Results from Test No. 1 in Third Concept Test Series

Steel Wire Rope Blasting Mat	Inside Mat Diameter (in)	Outside Mat Diameter (in)	Wire Rope Diameter (in)	Observed Damage
Inside Cylinder	27	32	0.75	All strands completely broken in regions opposite each munition, many wires frayed in strands around entire cross section with munitions
Outside Cylinder	36	41	0.75	No observable damage except for a few broken strands
Inside Mat Above Munition Baseplates	N/A	N/A	0.625	Several strands completely broken in region directly above munitions
Outside Mat Above Munition Baseplates	N/A	N/A	0.5	One strand completely broken in region directly above munitions
Inside Mat Below Munition Noses	N/A	N/A	0.625	No observed damage
Outside Mat Below Munition Noses	N/A	N/A	0.625	No observed damage

The inside mat above the munition baseplates also suffered severe damage. The strands directly above the munitions were severed. However, there was no other damage to the mat outside this localized region. The outside mat above the munition baseplates had one severed strand. The witness panel outside these mats had a single large hole, but it is hypothesized that this hole was caused by impact from a lifting lug on the outer blasting mat when blast pressures exiting through the top mats threw the outside top mat into the witness plate. The two blasting mats below the noses of the munitions were not damaged.

The damage caused to the inner cylindrical blasting mat and the inside mat above the munition baseplates was considered unacceptable. Evidently, the munitions were too close to the inner cylindrical mat, so that the blast pressures caused by the close-in standoff, combined with the effects of fragment impacts, exceeded the capacity of the steel strands near the munitions. The scaled standoff from each single munition to the closest point on the inner mat was approximately 0.84 $ft/lb^{1/3}$. If the explosion is idealized as a surface burst, where the symmetrical expansion of shock pressures from each munition is assumed to provide reflecting surfaces for the other munitions, the

peak reflected pressure on the mat opposite each munition was approximately 12,000 psi. The inner mat was also constructed with most of the wires running vertically, since this is a more optimal weave orientation for stopping most of the munition fragments. Therefore, the mat had relatively low hoop strength. The severe damage to the inside mat above the munition baseplates is thought to be caused by relatively large fragments from the baseplates of the three munitions striking in a very localized area. The scaled standoff to the inside mats above and below the three munitions was 1.2 ft/lb$^{1/3}$.

The last five tests in the third concept test series were performed with fragment mitigation materials including a single layer of steel wire rope blasting mats around the munitions backed up by solid 0.5 inch thick steel plate. For most of the tests, the fragment mitigation system also included 4 to 6 inches of sand placed around the munition(s). The single layer of blasting mats included a 36 inch high cylindrical mat around the munitions and two flat mats capping the top and the bottom of the cylindrical mat. The cylindrical mat was manufactured with continuously woven 0.75 inch diameter rope around the circumference and had a 36 inch inside diameter. The flat blasting mats were manufactured from 0.625 inch diameter rope. The top blasting mat over the munition baseplates was backed up with an 18 inch square, 0.5 inch thick, steel plate attached to the back side directly over the munitions. The cylindrical mat was backed up with a surrounding 0.5 inch thick solid steel cylinder. The results from Test 1 showed that fragments from the nose of the munitions caused virtually no mat damage and, therefore, no steel plate was used to back up the bottom blasting mat. Thin flat metal witness panels were used outside the top and bottom blasting mats, and the solid steel cylinder around the cylindrical blasting mat also served as a witness panel. Therefore, all fragment penetrations through the blasting mats were marked.

The blasting mats formed a self-supporting structure around the munitions, which were always centered around the vertical centerline through the mats. In Test 2, the munition was located halfway up the height of the cylindrical blasting mat. In all the subsequent tests, the munitions were placed six inches below the midheight position because Test 2 caused extensive localized damage around the circumference at midheight on the cylinder. Therefore, the damage to the mat caused by Tests 3 through 6 could be isolated, for the most part, from that caused by Test 2. In all tests with multiple munitions, the munitions were taped together side-by-side, so that maximum blast loads on the cylindrical blast mat occurred at 120 or 180 degree intervals around the circumference of the mat. In all tests, the munitions were tested without fuzes or cartridges and were detonated with 45 grams of C-4 explosive placed in the fuze well.

In Tests 3 through 6, the munitions were placed in a cylindrical plastic container filled with dry sand. The thickness of sand around the munitions varied. The sand thickness around the sides of munitions was not equal around the circumference of the container in cases where multiple munitions were detonated in a side-by-side configuration. Table 2.6 shows a summary of the test set-up and results for Tests 2 through 6. Minimum sand thicknesses around the sides of the munitions are shown in the table.

Table 2.6. Results from Test No. 2 through 6 in Third Concept Test Series

Test No.	Number of Munitions	Thickness of Sand Layer Around Munitions (in)	Observed Damage
2	1	No sand	Thin layer of severe damage in cylindrical blasting mat around circumference in cross section with munition. Outer steel plate cylinder surrounding mat had approx. 30 fragment hits with maximum penetration depth = 0.38".
3	1	6" top and bottom 8" around the side	Minimal damage to blasting mats. No observable damage to outer steel cylinder.
4	2	6" top and bottom 9" around the side	Minimal damage to blasting mats. Several minor fragment hits on outer steel cylinder (penetration depths less than 0.05").
5	3	6" all around	Minimal damage to blasting mats. Several minor fragment hits on outer steel cylinder (penetration depths less than 0.05").
6	3	4.5" all around	Minimal damage to blasting mats. Several minor fragment hits on outer steel cylinder (penetration depths less than 0.05").

The results in Table 2.6 show the very dramatic effect of a thin layer of sand around the munitions on the overall effectiveness of the fragment mitigating system. The single cross section which was exposed to Tests 3 through 6 had two areas where an entire rope was broken. Outside these areas, which may have been weakened during test No. 2, the mat was almost undamaged by these tests. The steel cylinder was hit with approximately 30 fragments during Test 2 with a maximum fragment penetration depth of about 0.38 inches. Many of the hits were caused by high angle fragments which evidently passed through voids in the mat. In Tests 3 through 6, when the munitions were surrounded by sand, the number of new fragment hits per test decreased to less than ten per test, and the maximum penetration depth decreased to less than 0.1 inch. Therefore, the vast majority of fragments were stopped by the mat, and fragments penetrating the mat did not have enough velocity to cause significant damage to the steel cylinder. No fragment penetrations occurred in the witness panels over the top and bottom mats during Tests 3 through 6.

In summary, the sand significantly slowed all the munition fragments so that both fragments hitting the mat and passing though the mat did much less damage than they otherwise would. The mat stopped the vast majority of the fragments, and the fragments that passed through the mat caused only slight damage to the surrounding steel plate. Test results from the second concept test series also showed that the steel wire rope blasting mats significantly reduced blast pressures on a

surrounding structure modeling the demolition container.

Based on the results from the third concept test series, a fragment mitigation system modeled after the system used in Tests 3 through 6 was recommended for the demolition container. A minimum sand thickness around the munitions of 4.5 inches was judged to be sufficient based on the results from Test 6.

3.0 CONCLUSIONS AND SUGGESTED MODIFICATIONS

As demonstrated in the subsequently performed proof test, the demil container met the requirements of the scope of work and provides the Army with an effective tool for OEW cleanup operations. Based on our observations during the tests, the following suggestions are made:

1. The cylindrical mat should be fabricated in sections, allowing the mat to be placed directly against the cylinder wall. This will provide a larger standoff from the charge and the wall will support the mat from the blast loading, thus reducing the blast damage. Also, individual sections of the mat can be replaced rather than replacing the entire mat; this will reduce the cost and effort for mat replacement.

2. For the prototype design, the containment vessel was built onto a working platform. The platform will then be placed on a trailer. It may be possible to fabricate the platform as a trailer. This could reduce the total cost of the system.